

1 METHOD FOR OPERATING AN INJECTION VALVE OF AN INTERNAL  
2 COMBUSTION ENGINE  
3

4 The present invention relates to a method for operating an injection valve of an  
5 internal combustion engine, whereby the metering of fuel is adjustable in  
6 particular by varying the stroke of the nozzle needle of the injection valve. The  
7 present invention also relates to a computer program and a control device for  
8 carrying out the method, and an internal combustion engine with a control device  
9 of this type.  
10

11 Background Information  
12

13 High-pressure fuel injection valves for direct fuel injection in the context of  
14 internal combustion engines are generally known. Specific types of high-pressure  
15 fuel injection valves 300, as shown in Figure 3, are also known, in particular, with  
16 which it is possible to meter the fuel to be injected into the combustion chambers  
17 of the internal combustion engine via the opening time of the valve, and, in  
18 particular, by varying the stroke of valve needle 330. With these valves, nozzle  
19 needle 330 is actuated, e.g., directly with the aid of a piezoelectric actuator 320.  
20 Valves of this type are suited in particular for transmitting very short injection  
21 pulses and a plurality of injection pulses during a single working cycle, i.e.,  
22 "multiple injection", within a very short time window. An example of a nozzle used  
23 with a valve of this type is the outwardly opening nozzle, i.e., the "A" nozzle.  
24

25 In the related art, the needle stroke with the injection valves described—which  
26 allow the nozzle needle stroke to be varied—is limited in terms of high values  
27 and low values for the valve stroke using diverse restrictions:  
28

29 The needle stroke is limited in terms of high values, for example, by  
30

- the possibilities for realizing a required small amount, because the nozzle surface and the fuel system pressure are specified by the combustion method used and are variable, although in a limited manner;
- the size of piezoelectric actuators 320 that can be inserted, and by their physical properties, such as their stroke capacity, the amount of force they can apply, their ability to accelerate, etc.; and by
- the capacity of the end stage of the control device (power dissipation, installation space).

In contrast, the needle stroke under rated operating conditions of the internal combustion engine, i.e., the nominal needle stroke in terms of small stroke values, i.e., in the form of a minimum needle stroke, is limited by

- the need to ensure an adequate scavenging effect.

The purpose of this minimum needle stroke is to ensure that, under rated operating conditions of the internal combustion engine, when the injection valve is operated primarily with the nominal stroke, a valve is prevented from closing incompletely or jamming open due to the presence of particles in the cross section of the injection nozzle.

The assurance of an adequate scavenging effect is particularly important because it prevents the risk of damage caused by a gasoline-filled cylinder. Damage caused by a gasoline-filled cylinder occurs when the cross section of the injection valve is blocked by dirt particles, thereby preventing the injection valve from closing completely. In this case, fuel is delivered continuously into the cylinder whose injection valve is jammed. Since fuel can be considered to be an incompressible medium, the piston motion is hindered or blocked when the amount of fuel injected exceeds the compression volume of the cylinder. If other cylinders in the internal combustion engine are functioning properly at this time, they exert—via the crankshaft—very strong forces on the connecting rod and the

piston of the blocked cylinder, which usually results in irreparable engine damage, particularly in the form of the connecting rod breaking and a damaged cylinder.

As described above, soiling of the nozzle with dirt particles is prevented via specification of the minimum needle stroke under rated operating conditions.

This specification of the minimum needle stroke applies only for the rated operating conditions of the internal combustion engine, however. It does not rule out the fact that the injection valve must also be closed completely at times between individual injection impulses and/or strokes of the nozzle needle. This applies in particular for operating states with a low fuel requirement, e.g., during idle, when the nozzle needle is actuated for a prolonged period of time not with complete strokes, as is the case under rated operating conditions, but only with partial strokes. In these operating states of the internal combustion engine, an adequate scavenging effect is no longer ensured, due to the partial-stroke actuation. This results in a greatly increased risk that the injection nozzle will become soiled and make it more difficult to detect such soiling.

During idle operation in particular, two injection cycles of a cylinder can be separated by a long period of time. As a result, only relatively few injection events are available for diagnosing the undesired jammed-open operating state of the nozzle needle; this makes diagnosis of this operating state less reliable overall.

Based on this related art, the object of the present invention is to further develop known methods for operating an injection valve of an internal combustion engine, known computer programs and control devices for carrying out this method, and known internal combustion engines with a control device of that type, such that soiling of the nozzle of the injection valve by particles and, associated therewith,

1 the risk of damage caused by a gasoline-filled cylinder, is more easily detected  
2 and prevented.

3

4 This object is attained by the subject of Claim 1. According thereto, the object of  
5 the invention is attained in particular by the fact that a method for operating an  
6 injection valve of an internal combustion engine, in which the metering of fuel is  
7 adjustable by varying the injection time and stroke of the nozzle needle of the  
8 injection valve, is composed of the following steps:

9

- 10 a) The internal combustion engine is monitored for proper functioning;  
11 b) A jammed-open operating state of the nozzle needle of the injection valve  
12 is detected, due to soiling in particular, whereby the nozzle of the injection  
13 valve cannot be closed any further by the nozzle needle, but it can be  
14 opened further; and  
15 c) The nozzle is scavenged with fuel by setting an essentially maximum  
16 stroke of the nozzle needle to remove the soiling.

17

#### 18 Advantages of the Invention

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20 Advantageously, dirt particles in the cross section of the injection valve are rinsed  
21 away by the large amount of fuel that acts in a case of scavenging of this type,  
22 and by the strong pressure that is then applied. The nozzle is then free of dirt  
23 particles and can be closed completely again. The risk of damage caused by a  
24 gasoline-filled cylinder is therefore prevented. By scavenging the nozzle, the  
25 original spray pattern of the nozzle is also restored, if it was previously impaired  
26 by the dirt particles. Restoration of the spray pattern results in improved  
27 efficiency of the internal combustion engine.

28

29 Exemplary embodiments for monitoring the internal combustion engine for proper  
30 functionality and detection of the jammed-open operating state of the nozzle  
31 needle are the subject of subclaims 2 – 4.

1 Importantly, it must also be possible for the embodiments proposed in these  
2 claims to be carried out simultaneously. To detect a jammed-open operating  
3 state, it is sufficient when one of the conditions for detection mentioned in Claims  
4 2 – 4 is met.

5  
6 Advantageously, the increased amount of fuel delivered with a complete stroke  
7 within the framework of scavenging can be compensated for by reducing the  
8 duration of actuation  $t_i$ .

9  
10 When the valve jams in an open position, fuel flows continuously into the  
11 combustion chambers of the internal combustion engine. This results in a level of  
12 engine torque that is higher than desired. Advantageous remedies for the  
13 occurrence of this undesired additional torque are the subject of Subclaims 6 – 8.

14  
15 To reduce excess amounts of fuel and prevent incorrect actuation of scavenging  
16 according to step c), it is advantageous when the execution of step c) is blocked  
17 for a predetermined period of time before it is allowed to continue.

18  
19 The object described above is also attained using a computer program and a  
20 control device for carrying out the method, and by an internal combustion engine  
21 using a control device of this type. The advantages of these means of attaining  
22 the object correspond to the advantages described above in terms of the method  
23 according to the present invention.

24  
25 Drawing

26  
27 The present invention is described in detail below in the form of various  
28 exemplary embodiments and will be described in greater detail with reference to  
29 the three figures associated with the drawing.

30

Figure 1 shows the method for operating an injection valve of an internal combustion engine according to the present invention;

Figure 2 shows an internal combustion engine with associated valve injection according to the present invention; and

Figure 3 shows an injection valve with variation of the stroke of the nozzle needle according to the state of the art.

#### Detailed Description of the Exemplary Embodiments

The method according to the present invention serves to prevent soiling of nozzle 310 of injection valve 300, in particular during operating states in which a small amount of fuel is required, such as idling.

To this end, the method according to a step Sa) provides that the internal combustion engine is monitored for proper functioning. This monitoring can take place via one of four methods, according to the present invention.

In one form of this monitoring, the air-fuel mixture of the internal combustion engine is monitored to determine when it becomes rich, as indicated by method step Sa1. The fuel mixture is determined to have become richer typically via a reduction in the lambda value for the cylinder involved.

According to a second form of monitoring the internal combustion engine, said internal combustion engine or any of its cylinders is monitored for the occurrence of misfires, as proposed in method step Sa2. In this case, a misfire is understood to mean absence of combustion during an ignition cycle.

In a third form of monitoring, proper functioning of the internal combustion engine can also be monitored by monitoring the pressure in a fuel accumulator 110

1 assigned to the internal combustion engine. If this pressure drops, proper  
2 operation of the internal combustion engine is not ensured (Sa3).

3  
4 Finally, according to a fourth method of monitoring, individual cylinders of the  
5 internal combustion engine are observed to detect increases in torque or torque  
6 irregularities (Sa4).

7  
8 All four of the monitoring methods described according to method steps Sa1,  
9 Sa2, Sa3 and Sa4 can be carried out alone or in any combination with each  
10 other. Reference to the possible combinations is made in some of the claims  
11 using the wording: “— possibly in addition —” and “— possibly also —”.

12  
13 Within the framework of the present invention, it makes sense to monitor the  
14 internal combustion engine only when the findings obtained by monitoring are  
15 also evaluated in terms of an undesired and detectable jammed-open operating  
16 state of nozzle needle 330 of injection valve 300. As shown in Figure 1, this  
17 evaluation is based on the monitoring of the internal combustion engine carried  
18 out previously in step Sa). For example, according to a method step Sb1 for the  
19 case in which the fuel mixture of the internal combustion engine was monitored  
20 according to method step Sa1 to determine whether it had become richer, a  
21 jammed-open operating state of the nozzle needle is detected when the richness  
22 of the fuel mixture is greater than a specifiable enrichment threshold value or  
23 when the gradient of the enrichment is greater than a specifiable enrichment  
24 gradient threshold value. In the same manner, when the internal combustion  
25 engine is monitored according to method step Sa2 to detect misfires, a jammed-  
26 open operating state of the nozzle needle is detected according to method step  
27 Sb2 when the number of misfires detected in a cylinder per unit of time exceeds  
28 a specifiable threshold for frequency. When the internal combustion engine is  
29 monitored according to method step Sa3 to detect a pressure drop in fuel  
30 accumulator 110, a jammed-open operating state of nozzle needle 330 is  
31 detected according to method step Sb3 when the pressure in fuel accumulator

1 110 falls below a specifiable threshold for pressure or when the course of  
2 pressure in fuel accumulator 110 over time deviates from a specifiable expected  
3 pressure gradient by more than a specifiable, expected course of pressure over  
4 time. Finally, when the internal combustion engine is monitored according to  
5 method step Sa4, torque increases or irregularities detected during stratified-  
6 charge operation indicate that a valve is not closing completely, i.e., they indicate  
7 a jammed-open operating state of nozzle needle 330 when the identified torque  
8 increases or irregularities exceed a specified threshold value.

9  
10 In method step Sb according to Figure 1, a check is carried out to determine  
11 whether a jammed-open operating state of nozzle needle 330 is detected, at  
12 least in accordance with one of the method steps Sb1, Sb2, Sb3 or Sb4. If this is  
13 not the case, the monitoring is continued according to method step Sa). If a  
14 jammed-open operating state of nozzle needle 330 is detected, however, i.e.,  
15 when it is detected that said nozzle needle is no longer capable of being closed  
16 but can be opened further, this indicates that nozzle 310 is soiled with particles.  
17 This deduction is allowed in particular when this jammed-open operating state  
18 does not occur on a regular basis, but rather only on a very temporary basis. In  
19 this case, an imperfectly-manufactured surface 310 of the nozzle can be ruled  
20 out as the cause of the jammed-open operating state.

21  
22 For the case in which a soiling of the cross section of nozzle 310 was detected in  
23 method step Sb), the method according to the present invention provides that  
24 nozzle 310 is scavenged with fuel according to method step Sc, whereby the  
25 stroke of nozzle needle 330 is adjusted to an essentially maximum value. A  
26 particularly large amount of fuel under high pressure then flows through the  
27 nozzle of the injection valve, which washes away the undesired dirt particles. The  
28 nozzle is then free of dirt particles once more and can be closed properly again,  
29 resulting in proper functioning of the internal combustion engine.

30

Due to the setting of the maximum stroke of the nozzle needle during the scavenging procedure in method step Sc) (scavenging stroke), a particularly large amount of fuel is injected into the combustion chamber of internal combustion engine 100. This amount of fuel can definitely be greater than a nominal amount of fuel, which is required under rated operating conditions of the internal combustion engine. In some cases, this excess amount of fuel causes the internal combustion engine to produce higher torque. If this higher torque is not desired, the method according to the present invention and shown in Figure 1 recommends various measures for offsetting the occurrence of this increased torque.

To accomplish this, it must first be determined in method step Sd) whether increased torque is even present. If it is, there is a first possibility, according to method step Sd1), for holding the torque of the internal combustion engine constant. According to this method, while scavenging is being carried out according to method step Sc), the duration of actuation  $t_i$ —during which time the maximum nozzle needle stroke is set—is reduced to the point at which the amount of fuel injected by the injection valve into the combustion chamber of internal combustion engine 100 does not exceed a specified mean amount of fuel. An alternative is a second possibility for holding the torque of the internal combustion engine constant. According to method step Sd2), while scavenging is being carried out according to method step c), a misfire is artificially induced during ignition in the cylinder in which the jammed-open operating state of nozzle needle 330 was detected. This misfire can be artificially induced by delaying the moment of ignition until the air-fuel mixture is no longer flammable and/or until the high-pressure efficiency of combustion is minimal.

Two further measures for holding the torque constant depend on the operating mode of the internal combustion engine.

If it is determined in a method step Sd') that internal combustion engine 100 is functioning in a "homogeneous operating condition", i.e., that slight increases in torque in accordance with the lambda efficiency curve are being produced, it is possible to hold the torque of the internal combustion engine constant by delaying the moments of ignition during scavenging until the ignition timing efficiency is adjusted according to the following formula (method step Sd3):

$$\eta_{zw} = (M_{d\_soll} / M_{i\_opt}) \cdot (1/\eta_{\lambda}),$$

with  $\eta_{\lambda} = f(\lambda)$ ,  $\lambda = r_l / r_{k\_soll}$ ; and

$$r_{k\_soll} = f(\text{scavenging stroke})$$

wherein

$\eta_{zw}$  is the ignition time efficiency;

$M_{d\_soll}$  is the target value for the engine torque and/or for the internal combustion engine (100);

$M_{i\_opt}$  is the optimum engine torque and/or the optimal torque of the internal combustion engine (100);

$\eta_{\lambda}$  is the  $\lambda$  efficiency;

$r_l$  is the air mass; and

$r_{k\_soll}$  is the target value for the fuel mass.

If it is determined in method step Sd', however, that internal combustion engine 100 is operating in a "stratified-charge mode", this generally means there is an excess amount of air. As a result, slight-to-considerable increases in torque are produced, depending on the current operating point on the lambda efficiency

1 curve, provided the mixture is flammable. In the case of stratified-charge  
2 operation, the torque can be kept constant by not carrying out at least some of  
3 the injection pulses—that normally take place during a multiple-injection cycle—  
4 before or after injection, according to method step Sc).

5  
6 If the internal combustion engine is operated in the stratified-charge mode and a  
7 jammed-open injection valve is detected, a changeover should be made to the  
8 homogeneous operating condition, since, in this mode, torque can be limited by  
9 limiting the air mass supplied.

10  
11 All approaches based on method steps Sd1), Sd2), Sd3) and Sd4) induce a  
12 limitation of the amount of fuel supplied to the combustion chambers of internal  
13 combustion engine 100, although the injection valve is opened to a maximum  
14 extent when it is operated with a scavenging stroke.

15  
16 Independently of which of the versions is used to hold the torque constant, it is  
17 recommended, after scavenging is carried out, to implement a pause of a  
18 predetermined period of time before carrying out scavenging once more; refer to  
19 step Se). In this manner, incorrect actuation of the method according to the  
20 present invention and, in particular, of the scavenging according to step Sc) is  
21 prevented.